Synthesis and characterization of Bio-composite

A dissertation submission in the partial fulfillment of

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Under academy autonomy

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By

Asit Sahoo

Under the supervision of

Dr. D.K. Bisoyi

DEPARTMENT OF PHYSICS

NATIONAL INSTITUTE OF TECHNOLOGY,

ROURKELA-769008

NATIONAL INSTITUTE OF TECHNOLOGY,

ROURKELA

CERTIFICATE

This is to certify that the thesis entitled "Synthesis and characterization of Bio composite" is submitted by Asit Sahoo in partial fulfillment for the requirements for the award of Master of Science degree in physics department at National institute of technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other institute/university for the award of any degree.

Place: Rourkela

Date:13.05.2011

Dr.D.K.Bisoyi

Department of physics

National Institute of Technology,

Rourkela-769008

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Place: Rourkela Asit Sahoo
Date: 13.05.2011

CONTENT

ABSTRACT

A eco-friendly biodegradable bio-composites were prepared using sisal fiber and starch using handmade mould. XRD patterns confirm that degree of crystallinity decrease with the increase in reinforcing material.SEM image says roughness surface structure of composites. FTIR study confirms that the composites are dewaxed and H_2O content is decreased. DSC scan confirms that the glass transition temperature of bio-composites is decreased with the increasing in concentration of reinforcing material.

LIST OF FIGURE

CHAPTER 1

1. INTRODUCTION

1.1. Overview of composites

Composites materials are made from two or more constituents materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure. Composites are made up of individual materials referred to as constituent materials. There are two categories of constituent materials referred: Matrix and reinforcement. At least one portion of the each type is required. The matrix materials surround and support the reinforcement materials by maintaining their relative positions. The reinforcement impacts their special mechanical and physical properties to enhance the matrix properties.

In the most general case a composite material consists of one or more discontinuous phases are distributed in continuous phase. In the case of several discontinuous phases of different natures of composites is said to be hybrid. The discontinuous phase is usually harder and with mechanical properties superior to those of the continuous phases. The continuous phase is called the matrix. The discontinuous phase is called the reinforcement, or reinforcing material.

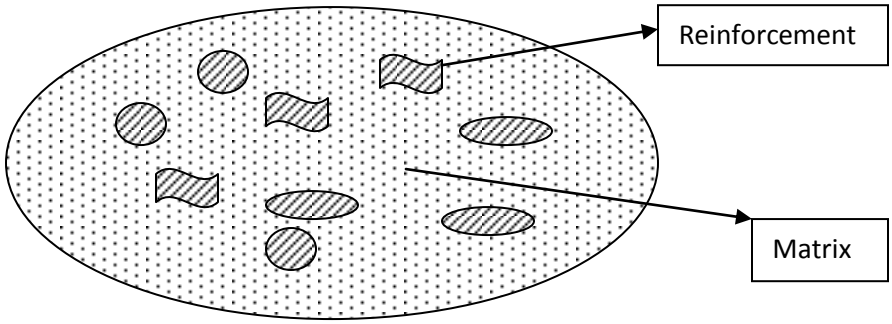

Fig.1: Composite

Composites are becoming an essential part in today's world because they offer advantage such as low weight, corrosion resistance, high fatigue strength, faster assembly etc. composites are used as materials in making aircraft structures to gulf clubs, electronic packaging to medical equipment and space vehicles to home building. Composites are generating curiosity and interest in students in all over the world. They are seeing everyday application of composites materials in the commercial market, and job opportunities are increasing in this field. The technology transfer initiative of the US federal government is opening new and large scale opportunities for use of advanced composites material.

1.2. Definition of composite

The most widely used meaning is the following one, which has been stated by Jartiz "Composites are multifunctional material systems that provide characteristics not obtainable from any discrete material. They are cohesive structures made by physically combining two or more compatible materials, different in composition and characteristics and sometimes in form". The weakness of this definition resided in the fact that it allows one to classify among the composites any mixture of materials without indicating either its specificity or the laws which should given it which distinguishes it from other very banal, meaningless mixtures. Kelly very clearly stresses that the composites should not be regarded simple as a combination of two materials. In the broader significance; the combination has its own distinctive properties. In terms of strength to resistance to heat or some other desirable quality, it is better than either of the components alone or radically different from either of them.

Beghezan defines as "The composites are compound materials which differ from alloys by the fact that the individual components retain their characteristics but are so incorporated into the composite as to take advantage only of their attributes and not of their short comings", in order to obtain improved materials.

Van Suchetclan explains composite materials as heterogeneous materials consisting of two or more solid phases, which are in intimate contact with each other on a microscopic scale. They can be also considered as homogeneous materials on a microscopic scale in the sense that any portion of it will have the same physical property.

1.3. Merits of Composites

The numerous features of composite materials have led to the widespread adoption and use through many different industries. It is because of the unique feature of the composites that people benefit. Below are some of the important features of composites and benefits they provide;

- Light weight

  Composites are incredibly light weight, especially in comparison to materials like concrete, metal and wood. Often a composite structure weigh is ¼ that of steel structure with same strength. That means a car made from composites can weigh ¼ that of car made from steel. This equates to serious fuel savings.

- High strength

  Composites materials are extremely strong especially per unit of weight. An example of this is high tenacity structural fibers used in composites such as amid and s-glass which are widely used in body amour. Due to high strength composites soldiers are protected from blasts and ballistic threats.

- Corrosion and chemical resistances
  Composites are highly resistance to chemicals and will never rust or corrode. That is why the marine industry is the first to adopt the use of composites. Boats are made with fiber glass, can stay in the highly corrosive salt water without rusting.
- Elastic
  Fiber reinforced composites have highly elastic properties. When one bends metal, it will yield or dent. However, composites are bent, they want to naturally snap back in to place. This feature is ideal for springs, is why composites are used in car leaf springs and in limbs of the archery bows.
- Non conductive
  Certain composites, such as composites made from fiberglass are non conductive. This is important because often a structure is needed that is strong, yet that will not conduct current. An example of this is ladders. Aluminum ladders can be electrocution hazards, while ladders made with fiber glass are not a risk if the ladder was to cross the power line.

1.4. Characteristics of the Composites

A composite material consists of two phases. It consists of one or more discontinuous phases embedded in a continuous phase. The discontinuous phase is usually harder and stronger than the continuous phase and is called the, reinforcement or reinforcing material, whereas the continuous phase is termed as the ‘‘matrix ‘‘. The matrix is usually more ductile and less hard. It holds the dispersed phase and shares a load with it. Matrix is composed of any of the three basic material type i.e. polymers, metals or ceramics. The matrix forms the bulk form or the part or product. The secondary phase embedded in the matrix is a discontinuous phase. It is usually harder and stronger than the continuous phase. It servers to strengthen the composites and improves the overall mechanical properties of the matrix. Properties of composites are strongly dependent on the properties of their constituent materials, their distribution and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way resulting in improved or better properties. Apart from the nature of the constituent materials, the geometry of the reinforcement (shape, size and size distribution) influences the properties of the composite to a great extent. The concentration distribution and orientation of the reinforcement also affect the properties. The shape of the discontinuous phase (which may by spherical, cylindrical, or rectangular cross-sanctioned prisms or platelets), the size and size distribution (which controls the texture of the material) and volume fraction determine the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix. Concentration, usually measured as volume or weight fraction, determines the contribution of a single constituent to the overall properties of the composites. It is not only the single most important parameter influencing the properties of the composites, but also an easily controllable manufacturing variable used to alter its properties.

1.5. Natural Fiber Reinforced Composites

The interest in natural fiber-reinforced polymer composite materials is rapidly growing both in terms of their industrial applications and fundamental research. They are renewable, cheap, completely or partially recyclable, and biodegradable. Plants, such as flax, cotton, hemp, jute, sisal, kenaf, pineapple, ramie, bamboo, banana, etc., as well as wood, used from time immemorial as a source of lignocellulosic fibers, are more and more often applied as the reinforcement of composites. Their availability, renewability, low density, and price as well as satisfactory mechanical properties make them an attractive ecological alternative to glass, carbon and man-made fibers used for the manufacturing of composites. The natural fiber-containing composites are more environmentally friendly, and are used in transportation (automobiles, railway coaches, aerospace), military applications, building and construction industries (ceiling paneling, partition boards), packaging, consumer products,etc.

1.6. Classification of Natural Fibers

Fibers are a class of hair-like material that are continuous filaments or are in discrete elongated pieces, similar to pieces of thread. They can be spun into filaments, thread, or rope. They can be used as a component of composites materials. They can also be matted into sheets to make products such as paper or felt. Fibers are of two types: natural fiber and man made or synthetic fiber.

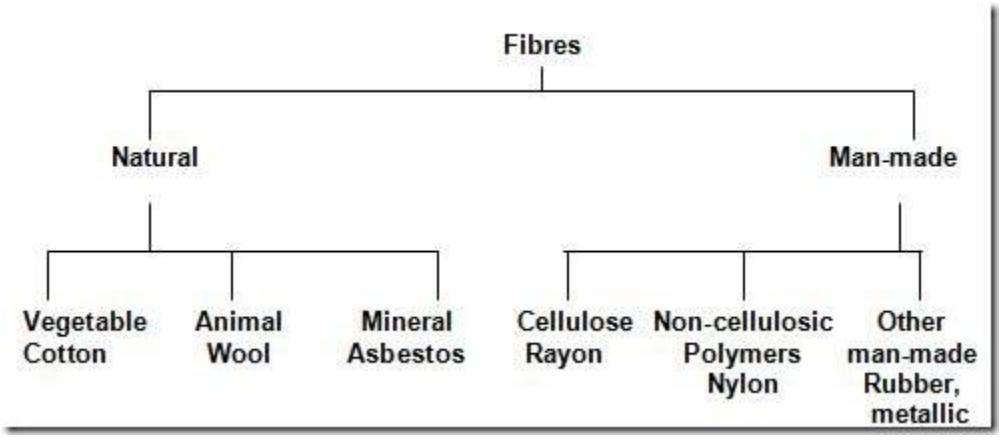

Fig 2: Classification of fibers

Natural fibers include those made from plant, animal and mineral sources. Natural fibers can be classified according to their origin.

- Animal fiber
- Mineral fiber
- Plant fiber

Animal Fiber

Animal fiber generally comprise proteins; examples mohair, wool, silk, alpaca, angora.

Animal hair (wool or hair): Fiber taken from animals or hairy mammals, i.e. Sheep's wool, goat hair (cashmere, mohair), alpaca hair, horse hair, etc.

Silk fiber: Fiber collected from dried saliva of bugs or insects during the preparation of cocoons. Examples include silk from silk worms.

Avian fiber: Fibers from birds, e.g. feathers and feather fiber.

Mineral fiber

Mineral fibers are naturally occurring fiber or slightly modified fiber procured from minerals. These can be categorized into the following categories:

Asbestos: The only naturally occurring mineral fiber. Variations are serpentine and amphiboles, anthophyllite.

Ceramic fibers: Glass fibers (Glass wood and Quartz), aluminum oxide, silicon carbide, and boron carbide.

Metal fibers: Aluminum fibers

Plant fiber

Plant fibers are generally comprised mainly of cellulose: examples include cotton, jute, flax, ramie, sisal and hemp. Cellulose fibers servers in the manufacture of paper and cloth. This fiber can be further categorizes into following.

Seed fiber: Fibers collected from the seed and seed case e.g. cotton and kapok.

Leaf fiber: Fibers collected from the leaves e.g. sisal and agave.

Skin fiber: Fibers are collected from the skin or bast surrounding the stem of their respective plant. These fibers have higher tensile strength than other fibers. Therefore, these fibers are used for durable yarn, fabric, packaging and paper. Some examples are flax, jute, banana, hemp, and soybean.

Fruit fiber: Fibers are collected from the fruit of the plant, e.g. coconut (coir) fiber.

Stalk fiber: Fibers are actually the stalks of the plant,i.e straws of wheat, rice, barley, and other crops including bamboo and grass. Tree wood is also such a fiber.

The natural fibers can be used to reinforce both thermosetting and thermoplastic matrices. Thermosetting resins, such as epoxy, polyester, polyurethane, phenolic, etc. are commonly used today in natural fiber composites, in which composites requiring higher performance applications. They provide sufficient mechanical properties, in particular stiffness and strength, at acceptably low price levels. Considering the ecological aspects of material selection, replacing synthetic fibers by natural ones is only a first step. Restricting the emission of green house effect causing gases such as CO_2 into the atmosphere and an increasing

awareness of the finiteness of fossil energy resources are leading to developing new materials that are entirely based on renewable resources.

1.7. Applications of Natural Fiber Composites

The natural fiber composites can be very cost effective material for following applications:

- Building and construction industry: panels for partition and false ceiling, partition boards, wall, floor, window and door frames, roof tiles, mobile or pre-fabricated buildings which can be used in times of natural calamities such as floods, cyclones, earthquakes, etc.
- Storage devices: post-boxes, grain storage silos, bio-gas containers, etc.
- Furniture: chair, table, shower, bath units, etc.
- Electric devices: electrical appliances, pipes, etc.
- Everyday applications: lampshades, suitcases, helmets, etc.
- Transportation: automobile and railway coach interior, boat, etc.
- The reasons for the application of natural fibers in the automotive industry include:
- Low density
- Acceptable mechanical properties, good acoustic properties.
- Favorable processing properties, for instance low wear on tools, etc.
- Options for new production technologies and materials.
- Favorable accident performance, high stability, less splintering.
- Favorable ecobalance for part production.
- Favorable eco balance during vehicle operation due to weight savings.
- Occupational health benefits compared to glass fibers during production.
- No off-gassing of toxic compounds (in contrast to phenol resin bonded wood and recycled Cotton fiber parts).
- Reduced fogging behavior.
- Price advantages both for the fibers and the applied technologies.

1.8. Advantages of Natural Fiber Composites

The main advantages of natural fiber composite are:

- Low specific weight, resulting in a higher specific strength and stiffness than glass fiber.
- It is a renewable source, the production requires little energy, and CO_2 is used while oxygen is given back to the environment.
- Producible with low investment at low cost, which makes the material an interesting product for low wage countries.
- Reduced wear of tooling, healthier working condition, and no skin irritation.
- Thermal recycling is possible while glass causes problem in combustion furnaces.
- Good thermal and acoustic insulating properties.

CHAPTERR 2

2. LITERATURE SURVEY

The history of mankind has witnessed several surges in the field of research and development. The rampant use of petroleum product has created a twin dilemma; depletion of petroleum resources and entrapment of plastics in the food chain and environment. The increasing pollution caused by the use of plastics and emissions during incineration is affecting the food we eat, water we drink, air we breathe and threatening the greatest right of human beings, the right to live. The exhaustive use of petroleum based resources has initiated the efforts to develop biodegradable plastics. This is based on renewable biobased plants and agricultural products that can be compete in the market currently dominated by the petroleum based products. The production of 100 percent biobased materials as substitute for petroleum based products is not an economical solution. A more viable solution would be to combine petroleum and biobased resources to develop a cost effective product having immense application. Scientists are looking at the various possibilities of combining natural fibers such as sisal, flax,hemp,jute,banana,wood and various grasses with polymer matrices from non-renewable and renewable resources to form composite materials to make the biocomposite revolution a reality.

Biocomposites derived from plant derived fibre and bio derived plastics are likely to be more ecofriendly and such composites are termed as green composites.

The best known renewable resources capable of making biodegradable plastics are starch and cellulose. Starch is one of the least expensive biodegradable materials available in the world market today. It is a versatile polymer with immense potential for use in non-food industries. Cellulose from trees and cotton plants is a substitute for petroleum feed stocks to make cellulose plastics. Another aspect that has been gained global attention is the development of biodegradable plastics from vegetables oil like soybean oil, peanut oil, wal nut oil, sunflower oil. Green composites from soy protein based bioplastics and natural fibers show immense potentials for rigid packing and housing and transportation applications. Fish oil based polymers have also attracted the attention of researchers due to their high degree of instauration. Fish oil based polymers also possess unique good damping and shape memory properties.

CLASSIFICATION OF BIO-COMPOSITES

1. GREEN COMPOSITES:

Research efforts are currently being harnessed in developing a new class of fully biodegradable “green” composites by combining (natural /bio) fibres with biodegradable resins.The major attraction about green composites are that they are environmentally-friendly, fully degradable and sustainable, i.e. they are truly green in every way. At the end of their life, they can be easily disposed of or composed without harming the environment.

Another important biocomposite category is based on agro polymers matrixes, mainly focused on starchy materials. Plasticized starch, the so called "thermoplastic starch"(TPS) is obtained after disruption and plasticization of native starch, with water and plasticizer by applying thermo mechanical energy is a continuous extrusion process. Unfortunately, TPS shows some drawbacks such as a strong hydrophilic character (water sensitive), rather poor mechanical properties compared to conventional polymers and an important post processing variation of the properties. To improve these material weaknesses, TPS is usually associated with other compounds. Green composites have been used in many applications such as mass produced consumer products with short life cycle or product intend for one time or short time use before disposal. Green composites may also be used for indoor applications with useful life of several years.

2. HYBRID COMPOSITES

The incorporation of several different types of fibers in to a single matrix has led to the development of hybrid biocomposite. The behavior of hybrid composites is weighed sum of the individual components in which there is a more favorable balance between the inherent advantage and disadvantages. Also, using a hybrid composite that contains two or more types of fibre,the advantage of one type of fiber could com lament with what are locking in the other. As a consequence, a balance in cost and performance could be achieved through proper material design. The properties hybrid composite mainly depend upon the fiber content, length of individual fiber, extent of intermingling fibre,fibre to matrix bonding and arrangement of both the fibers. The strength of the hybrid composite is also dependent upon the failure strain of the individual fibers. Hybrid composites can be designed by the combination of a synthetic fibre and a combination of two natural fiber in a matrix.

2.1 **Objectives of the Research Work**

The objectives of the project are outlined below.

- Fabrication of sisal fiber reinforced starch based composite.
- Microstructure of composite using SEM technique.
- XRD characteristics of composite.
- FTIR study of composite.
- DSC study of composite.

CHAPTER 3

3. MATERIALS AND METHODS

3.1: INTRODUCTION

This chapter describes the details of processing of the composites and the experimental procedures followed for their characterization and tribological evaluation. The raw materials used in this work are

- SISAL FIBER
- CASSVA STARCH

SISAL FIBRE

Sisal fiber is obtained from the leaves of the plant AGAVE SISALANA which was originated from Mexico and is now mainly cultivated in East Africa, Brazil, Haiti, India and Indonesia. It is grouped under the broad heading of the "hard fibers" among which sisal is placed second to maintain durability and strength.

Fig.3: Sisal fiber

The name "sisal" comes from a harbor town in Yucatan; Maya, Mexico .It means cold water. Agave plants were grown by the Maya Indians before the arrival of the Europeans. They prepared the fibers by hand and used it for ropes, carpets and clothing. It is one of the most extensively cultivated hard fibre in the world and it accounts for half the total production of textile fibres .The reason for this is due to the ease of cultivation of sisal plants, which have short renewing times, and is fairly easy to grow in all kinds of environments. A good sisal plant yields

about 200 leaves with each leaf having a mass composition of 4% fibre, 0.75% cuticle, 8% other dry matter and 87.25% moisture. Thus a normal leaf weighing about 600g yields about 3% by weight of fibre with each leaf containing about 1000 fibres. The fibre is extracted from the leaf either by retting, by scraping or by retting followed by scraping or by mechanical means using decorticators .The diameter of the fibre varied from 100mm to 300mm .The characteristics of the sisal fibres depend on the properties of the individual constituents, the fibrillar structure and the lamellae matrix. The fibre is composed of numerous elongated fusiform fibre cells that taper towards each end. The fibre cells are linked together by means of middle lamellae, which consist of hemicelluloses, lignin and pectin.

CASSVA STARCH

The cassava root is long and tapered, with a firm, homogeneous flesh encased in a detachable rind, about 1mm thick, rough and brown on the outside. Commercial varieties can be 5 to 10 cm in diameter at the top, and around 15 cm to 30 cm long. A woody cordon runs along the root's axis. The flesh can be chalk-white or yellowish. Cassava roots are very rich in starch, and contain significant amounts of calcium (50 mg/100g), phosphorus (40 mg/100g) and vitamin C (25 mg/100g). However, they are poor in protein and other nutrients. In contrast, cassava leaves are a good source of protein, and are rich in the amino acid lysine, though deficient in methionine and possibly.

Starch consists of amylose and amylopectin branch, which is base for adhesives, particularly those designed to bond paper in some form to itself or to other materials such as glass, mineral wool, and clay. Starch can also be used as a binder or adhesive for non paper substances such as charcoal in charcoal briquettes, mineral wool in ceiling tiles and ceramics before firing. The starches most commonly used for the manufacture of adhesive pastes are maize, potato, and cassava.. Cassava starch adhesives are more viscous and smoother working. They are fluid, stable glues of neutral pH that can be easily prepared and can be combined with many synthetic resin emulsions. Corn and rice starches take a much longer time to prepare and a higher temperature to reach the same level of conversion. For top-quality work, cassava starch is thought to be ideal, because it is slightly stronger than a potato starch adhesive while being odorless and tasteless, excellent as an adhesive for postage stamps, envelope flaps, and labels. Certain potato pastes have bitter tasting properties while cereal starches exhibit a cereal flavor.

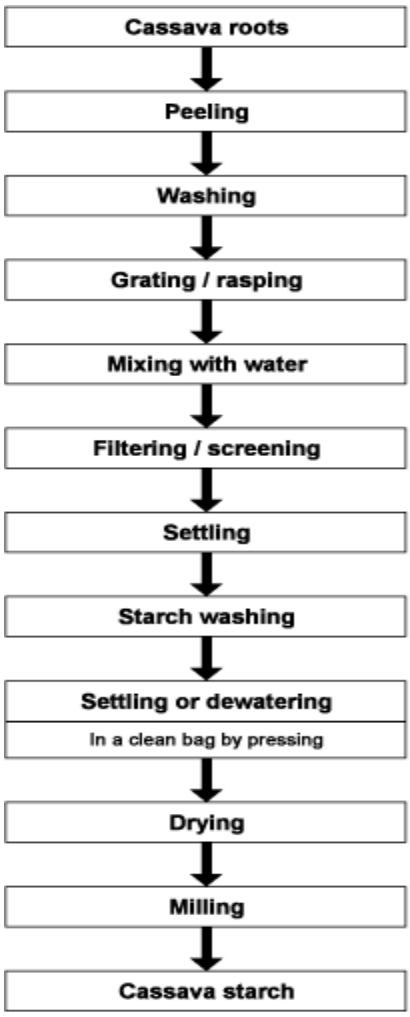

Fig.4: Processing cassava starch

The cassava starch for the present experimental work has been collected Varalaxmi Starch Industries (P) ltd SALEM (TN),INDIA.

3.2: **PROCESSING OF COMPOSITES**

The composite was prepared by solution mixing technique. At first, very small pieces of sisal fiber had been cut i.e. as small as possible. Then required amount of starch is dissolved in 10 ml water and stirred using stirrer. After 10 minute, the mixture was then dried in a micro wave oven at 160W temperature for 1 minute and 30 second. When the mixture turns into semi-liquid state, it was poured into a handmade mould and pressure was given from all sides. Then again the sample was completely dried up in an oven at 80^0 Celsius for 4 hour .Composites were made by maintain constant starch concentration and with varying fiber concentration. Water concentration kept remains same for all composites. Composites containing 100, 83.3, 71.4 percent by weight of sisal fiber, whereas starch was kept 1.25 gm by weight. All the composites are made in same process by maintaining heating time in microwave oven for 1 minute 30 second and drying time in oven for 4 hour at 80^0 Celsius.

Schematic diagram of sample preparation

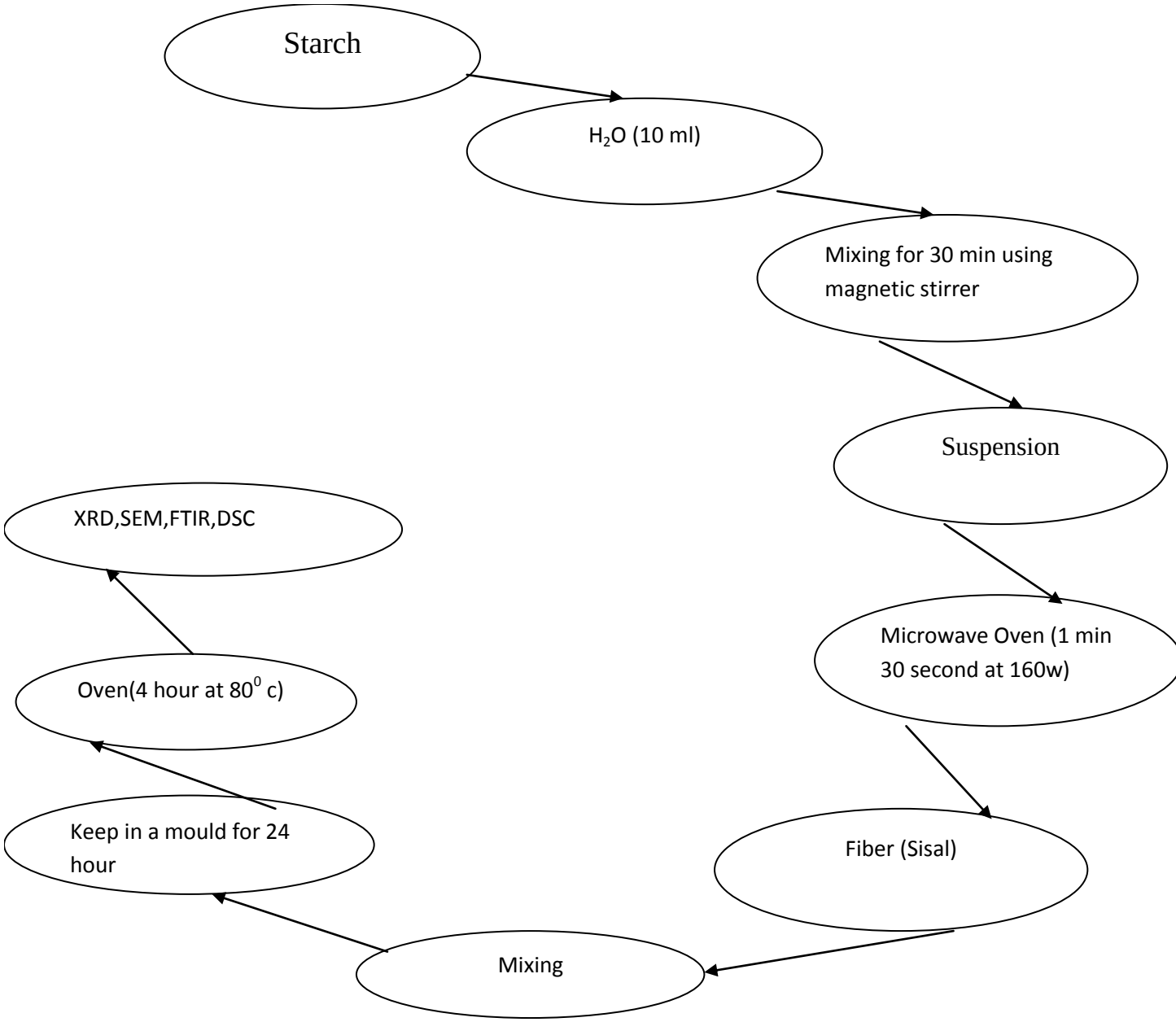

Fig.5: Schematic diagram of synthesis of composite

4. RESULTS AND DISCUSSION

4.1 **XRD ANALYSIS**

XRD analysis was studied using the room temperature powder X-ray diffraction (Model: PW 1830 diffractometer, Phillips, Netherland) with filtered 0.154 nm Cu Kα radiation. Samples are scanned in a continuous mode from 10° – 70° with a scanning rate of 2^0/minute.

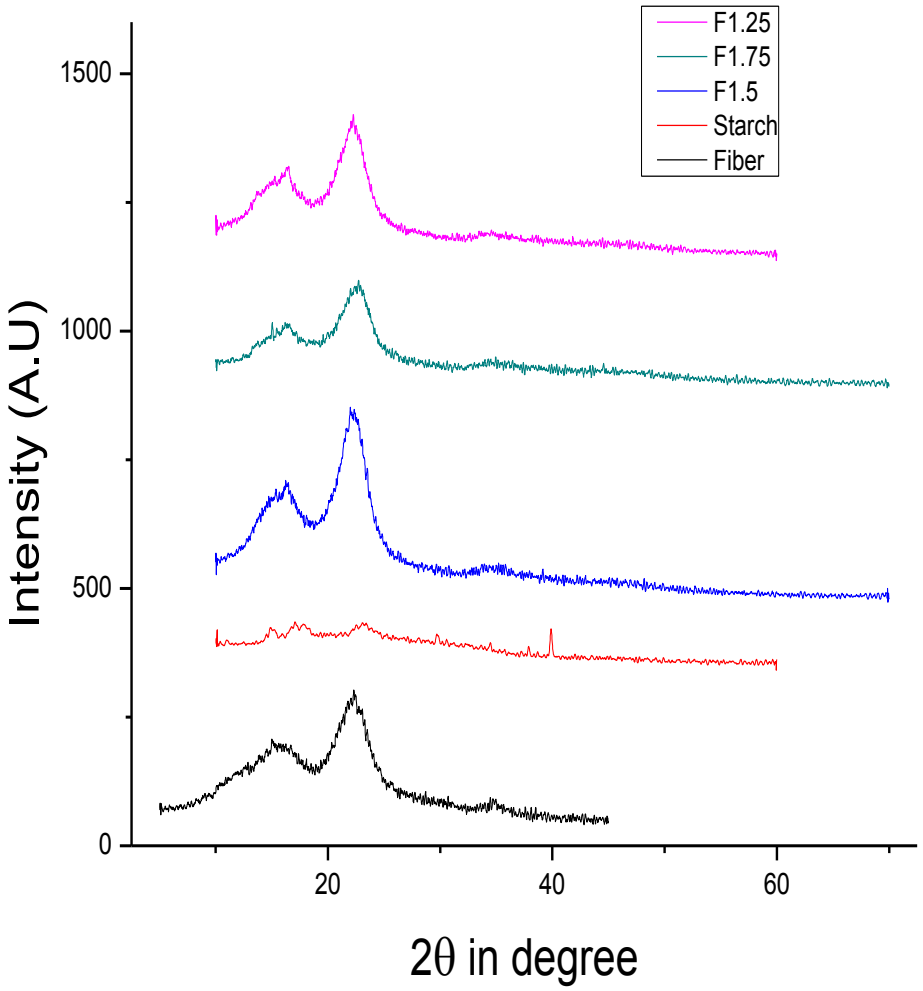

Fig.6: XRD ANALYSIS

- From XRD analysis we found that crystallite size of F1.25 is 3.6 nm and degree of crystallinity is 58.45.
- Crystallite size of F1.5 is 3.3 nm and degree of crystallinity is 56.22.
- Crystallite size of F1.75 is 4.9 nm and degree of crystallinity is 54.45.
- From the above result, it shows that with the increase in the percentage of fiber in the bio composite the degree of crystallinty of the composite decreases. It may be concluded that with the more reinforcement, the orientation of fiber is lowered which results in the decrease in the crystallinty. The peak observed in the composite is solely due to reinforcing material.

4.2 **SEM ANALYSIS**

Microstructural features were studied using Scanning Electron Microscope (JSM 6480 LV JEOL, Japan). The SEM microstructure of all samples is given in figure 7, 8, 9. The changes in the morphology of bio degradable matrix surfaces were studied with different concentration of fiber with cross linked cassava starch matrix. It was observed that the surfaces of matrix undergoing biodegradation. The three dimensional network of the composite and the cracks were observed here. The morphological changes of starch composites were occurred and sample surfaces became heterogeneous and rough.

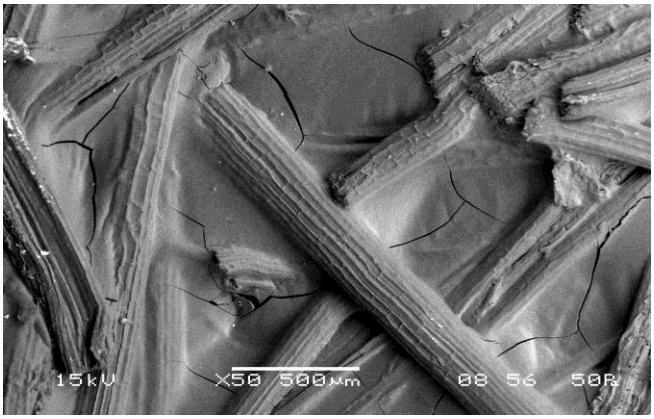

Fig.7: F1.25

In case of F1.25 composite, the wetting of fiber is well distributed in starch. Fibers are tightly bound with starch. They attract each other and after alignment they dry up which results cracks.

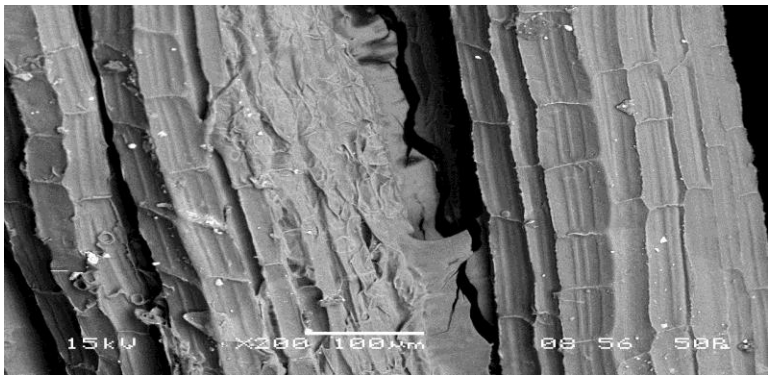

Fig.8:F1.50

This figure shows that roughness of the composite. It clearly indicates that there is a hole between composite. In this case, fibers are not tightly bounded with each other. In case of F1.50, due to increase in concentration of fiber, lack of proper wetting, hole is created in composites.

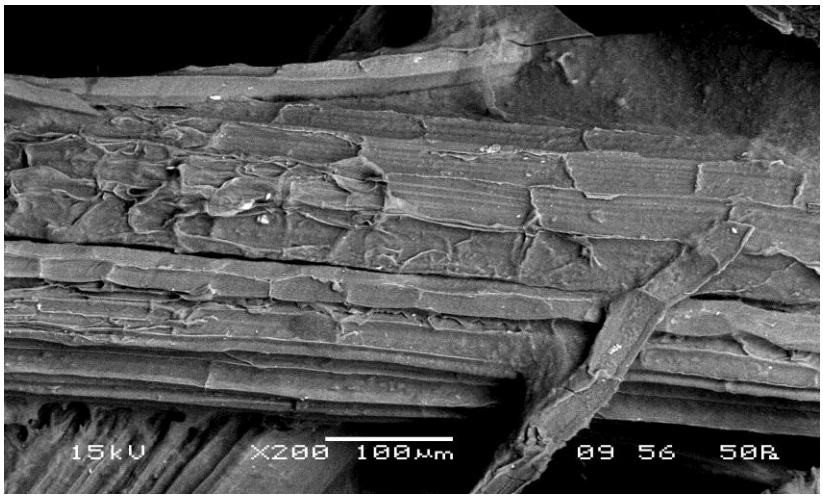

Fig.9: F-1.75

In case of composite F1.75, surfaces become very heterogeneous and rough. Here fiber concentration is much more than starch, so the reinforced fiber comes out of the composites due to rupture of matrix. It was observed that surfaces of the matrix undergoing bio degradation which was highly rough.

4.3 **FTIR ANALYSIS**

Fourier Transform Infrared Spectroscopy (FTIR) is an analytical technique used to identify mainly organic materials. FTIR analysis results in absorption spectra which provide information about the chemical bonds and molecular structure of a material. The FTIR imaging was performed in AIM-800 Automatic Infra red Microscope (SHIMADZU).

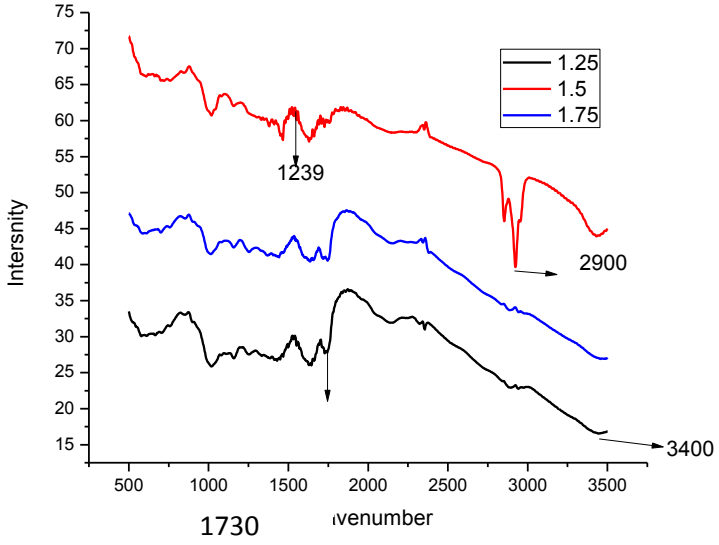

Fig.10: FTIR Plots

- From FTIR analysis it was observed that there is a sharp peak at 2900 cm-1 in case of composite F1.5 which indicates that that is associated with wax. In case of F1.75 and F1.25, composites dewaxed due to microwave radiation at the time of mixing.
- Peak at 3400 cm-1 indicates that the peak is associated with O-H bond. In case of F1.75 O-H bond is bond, but water content is less due to microwave radiation at the time of mixing and due to inter molecular hydrogen bonding.
- The C-H stretch at 2900 cm^{-1} is present in all fibers. So peak corresponds to 2900 cm^{-1} is due to reinforcement material.
- 1239 cm^{-1} peak is responsible for C-O-C stretching vibration.
- The carbonyl peak at 1730 cm^{-1} can be seen in all fibers. A sharp peak appeared at 1650 cm^{-1} is due to bending vibration water molecules.

4.4 **DSC ANALYSIS**

The DSC analysis of all the three samples is carried out using differential scanning calorimetric by heating the sample at 10 °C/min from 0^0c to 150^0c in argon in a thermal analyzer (Netzsch, Germany). The plots are shown in the figure 11, 12, 13.

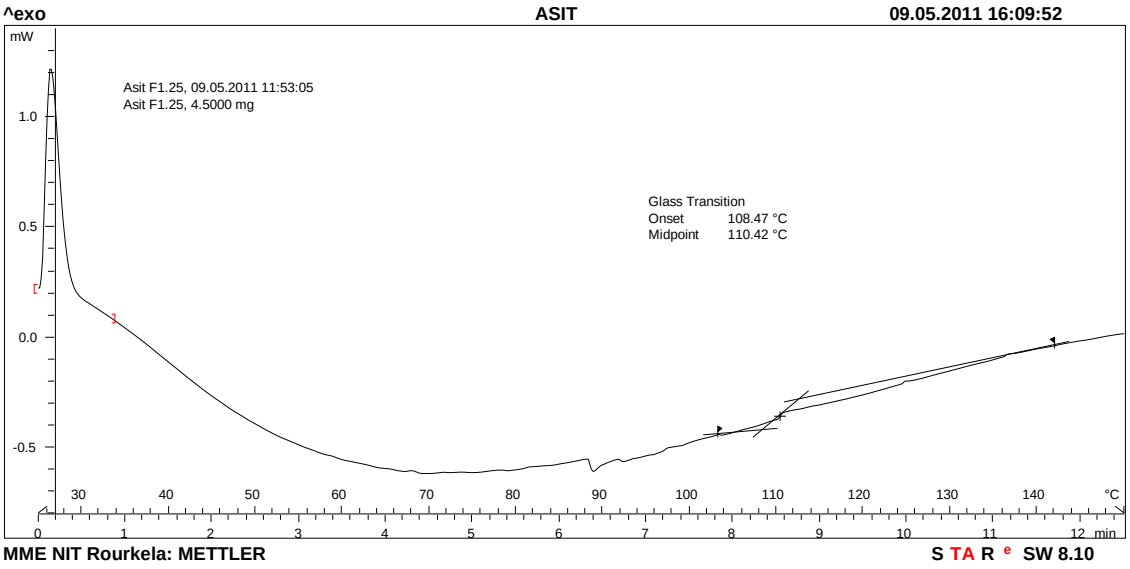

Fig.11:DSC scan of F1.25

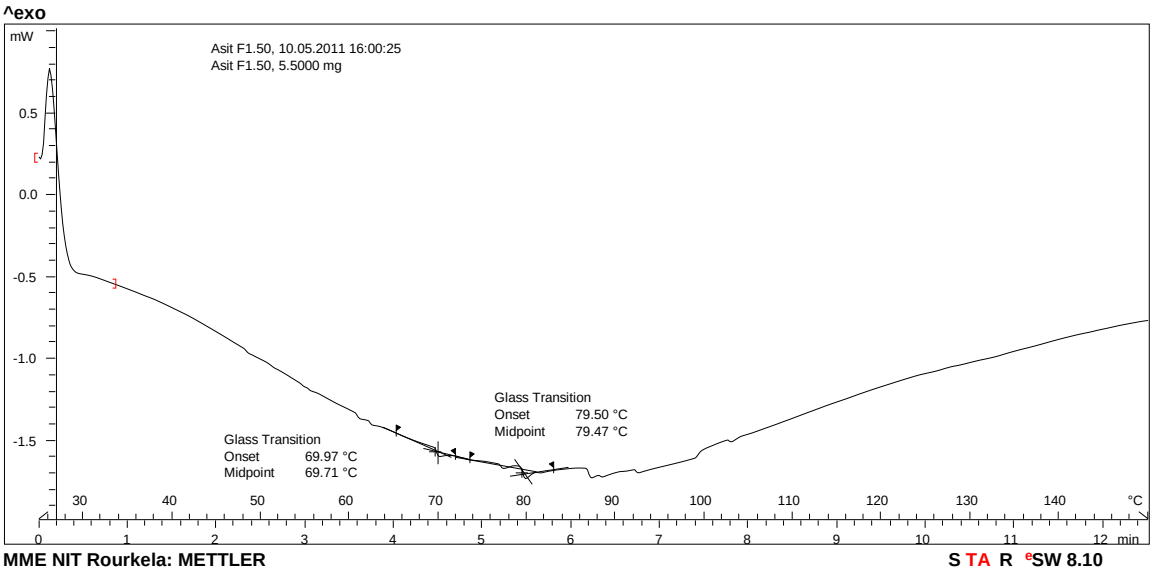

Fig.12: DSC scan of F1.50

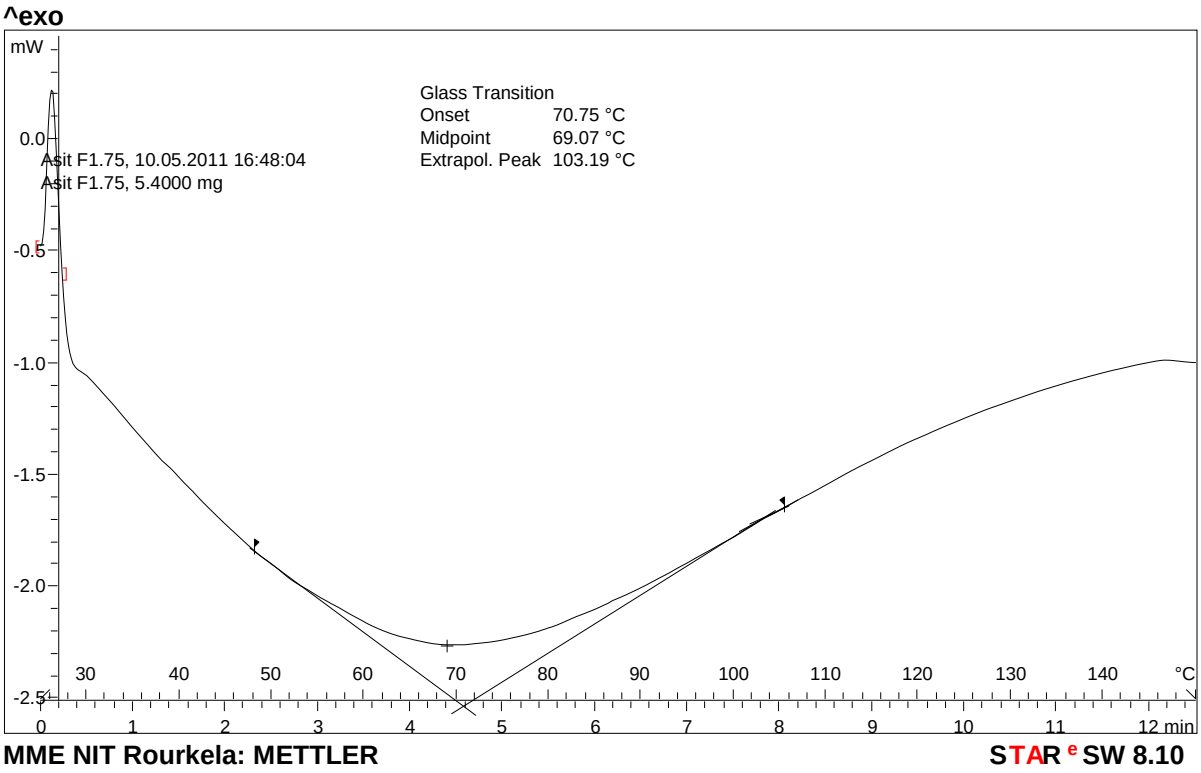

Fig.13: DSC scans of F1.75

Fig.11, 12, 13 shows the DSC thermal traces for the thermoplastic starch based composite. The glass transition in F1.25 is 110.42^0c. In case of F1.50, two transitions were detected; one is 69.71^0c and 79.47^0c. The glass transition is 69.07^0c in case of F1.75.The results of DSC experiments indicate an interaction between the fiber and the starch, causing the reduction of glass transition temperatures of the matrix in the composite. The glass transition temperature of the composites decreases with the increase in concentration of reinforcing material. From figure above observed value of Tg is influenced by the distribution and percentage of fiber in composite. The observed behavior could be explained by the dependence of Tg on molecular mobility and free volume in polymer. Intact, higher the percentage of fiber in sample, decreases the free volume and molecular mobility, which results in decreasing Tg. Decrease in Tg indicates that composites change from crystalline to rubbery phase.

5. **CONCLUSION**

In this study, we synthesized the bio-composite and study the nature of composites by varying fiber concentration with starch. Bio-composites were prepared with the help of sisal fiber and cassava starch using handmade mould. XRD patterns confirm that with the increase in the percentage of fiber in the bio composite the degree of crystallinity of the composite decreases. SEM micrograph shows degradation of the matrix at higher concentration of fiber. FTIR spectra confirms that water content of composites decreases due to intermolecular hydrogen bonding and dewaxed due to microwave radiation. DSC scan confirms that the glass transition temperature of the composites decreases with the increase in concentration of reinforcing material due to decrease in free volume and molecular mobility.

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